COSMIC EXTREMES: PROBING ENERGETIC TRANSIENTS WITH RADIO OBSERVATIONS

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Midwest Workshop on Supernovae and Transients
• **Transient events** reveal **jet evolution** from birth to death

• Jets and outflows let us probe extreme physical processes:
  – The end states of massive stars
  – Black hole formation and growth

• **Open questions:**
  – How exactly do relativistic jets and outflows form? What physical conditions are required?
  – What is the jet structure?
Radio Galaxy Hercules A
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Radio observations of transients **uniquely** constrain:

- Localization
- Velocity / energy scale
  - Beaming
  - radius constraints and size evolution
- Ambient density profile
- Magnetic field strength/outflow line-of-sight orientation (via polarization)
• VLA, ATCA, ALMA, LOFAR, MWA, ASKAP, MeerKAT, etc.
• To date: surveying large areas of the sky at high sensitivity and resolution is difficult, very time consuming
  – Most radio transients are discovered first at other wavelengths
• Future: era of all-sky radio surveys, real-time transient searches (SKA, others)
  – A better understanding of known radio transient populations will inform survey strategies
Tidal Disruption Events (TDEs)

- Reprocessing from stellar matter & ISM → emission lines
- Inspiral of compact objects → GWs
- Squeezing/disruption of star
- Interaction of unbound gas with ISM
- Accretion phase → luminous flare, sometimes: jet formation
- Stream-stream collisions → shocks

artist's view; NASA/CXC/M. Weiss/Komossa et al. 2004
Outflows Generate Synchrotron Emission

Slide courtesy T. Laskar
Outflows Generate Synchrotron Emission

Energy, $E_K$
Density, $n$
Shock physics ($\varepsilon_e$, $\varepsilon_B$)

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Outflows Generate Synchrotron Emission

TDE Swift J1644+57

Eftekharie et al. (2018)
TDE Radio Observations (2019)

- On-axis jet
- Off-axis jet
- Non-relativistic outflow

Luminosity (erg/s) vs. Time since Disruption/Discovery (years)
• Discovered November 22, 2014 by the ASAS-SN survey
• Nearby (~90 Mpc)

\begin{itemize}
  \item X-ray, UV, optical observations are consistent with previous TDEs, rule out AGN, supernova (Holoien et al. 2016, Miller et al. 2015)
\end{itemize}

\textit{Holoien et al. (2016)}
The emission is best modeled as the sum of a steady source with $F \alpha \nu^{-1}$ (dashed line) and a transient component (right panel).

- The steady component is broadly consistent with archival detections in 1993 and 1999.
A Non-Relativistic Outflow

**Timing of super-Eddington phase (X-ray/UV/optical model)**

- $t_{0,\text{radio}}$
- $t_{\text{peak} \dot{M}}$
- $t_{0, \dot{M} > \dot{M}_{\text{Edd}}}$

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**Equation:**

\[ E \sim (4-10) \times 10^{47} \text{ erg} \]

**Graphs:**

- Equi-partition radius (cm)
- Equi-partition energy (erg)

**Dates:**

- Mar 30, 2014
- Apr 27, 2014
- May 25, 2014
- Jun 22, 2014
- Jul 20, 2014
- Aug 17, 2014
- Sep 14, 2014
- Oct 12, 2014

*Alexander et al. (2016)*
The radio emission reveals a non-relativistic outflow, launched when the accretion rate was (mildly) super-Eddington.
Circumnuclear Density Profiles

\[ \text{Density (cm}^{-3}\text{)} \]

\[ \text{Radius [R/R}_{\text{sch}}] \]

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ASSASN – 14li (Conical)

Milky Way GC

XMMSL1 J0740 – 85 (Conical)

Sw 1644 + 57

M87

Eftekhari et al. (2018)
To probe the highest densities, we must go to the mm

ALMA observations of new TDEs are underway (PI: Alexander)

Long-term goal: placing TDEs in broader context of AGN variability

Within the next five years, we will know what fraction of TDEs produce relativistic jets and outflows.
**Summary**

- The radio properties of “extreme” transients reveal new physical insights and discoveries:
  - The **first** non-relativistic outflows detected in TDEs
  - Steep $r^{-2.5}$ density profile around TDE ASASSN-14li
  - mm observations are key: some TDEs may produce no outflows/radio emission
    - *Alexander et al. in prep*

- Radio transient science is poised for revolution
  - VLA, ALMA, upcoming facilities (SKA, ngVLA), synergies with new GW and multi-wavelength capabilities
  - VLA Sky Survey, ThunderKAT, etc: **discovery** of transients in the radio band
• VLA Sky Survey
  – All sky coverage north of declination -40°
  – Survey rms ~69 $\mu$Jy/beam
  – 9.7 million extragalactic source detections predicted

• Square Kilometer Array
  – ThunderKAT: SKA precursor radio transients survey